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TRANSLATION

IONIZATION METHODS OF OBTAINING
HIGH VACUUM

By

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Ionization Methods of Obtaining High Vacuum

by

Prof. Reykhrudel' and G. V. Smirnitskaya

The requirements of modern physics, chemistry and technological branches connected with them led to the development of new methods for the obtainment of high vacuum. As is known, under high vacuum we understand rarefaction of gas, at which the pressure is lower than 10^{-5} mm Hg[1].

Upon the degree of attained vacuum depends substantially the operational stability and service life of various electronic and ionic instruments, widely employed in radio engineering, nuclear physics and in numerous measuring and control systems. For example, a technologically correctly manufactured radio tube can serve for a period of 10-20 thousand hours, while a tube, manufactured without adherence to vacuum technology requirements, is out of order within 500-600 hours.

To attain high vacuum the two-stage pumping method is used everywheres. The gas, removed from the exhausted volume is discharged not directly into the atmosphere, but into a chamber where a reduced pressure of the order of 10^{-3} mm Hg was created by the pump of the first stage, so-called fore-vacuum pump, representing the development of an ordinary piston pump.

Of basic interest are high vacuum pumps. In laboratory practice up until recently were used mercury condensation pumps. The flow of heated mercury vapors in them comes out at greater velocity from the narrow tube (diffuser) and drags along gas molecules

1. See for example S. Deshman. Scientific Bases of Vacuum Technique, Publication of Foreign Literature 1950; N. A. Kaptsov; Technique of High Vacuum PRIRODA 1954, No. 4, pp. 33-44

into the cooling condensation chamber, from where they are removed by the forevacuum pump. A definite role in the pumping, particularly at much higher vacuum, plays also the sorption[1] of gas molecules on the surface of mercury droplets and subsequent liberation of same when the droplets fuse together in the condensation chamber.

Since the pressure of saturated mercury vapors at room temperature reaches the order of 10^{-3} mm Hg, then to attain much lower pressures (10^{-6} mm) it is necessary to freeze out the mercury vapors. This is realized by using special traps, the walls of which are cooled with liquid air or other media.

Oil diffusion pumps, which appear to be a modification of mercury pumps, work on organic oils with a vapor pressure of the order of 10^{-6} mm Hg and allow without freezing out of vapors to obtain much higher vacuum. But in many instances the operation of the electronic devices is disrupted by the presence of even small traces of oil vapors; freezing out is also necessary in this case.

In recent years was explained the possibility of obtaining high vacuum with the aid of installations , containing no working liquids, - so-called ion pumps. In these pumps the gas ionizes in an electric discharge. The ions are then removed from the discharge by two methods: either by forcing in the direction of the forevacuum by an electric field, or by sorption of ions and molecules on walls and electrodes of the discahrge tube.

The process of pushing out lies in the fact, that the positive ions are directed by the electric field toward a negatively charged cathode, they become neutralized on it and then removed by the forevacuum pump. In order that the pushing out should lead to removal by pumping, the number of ions, moving toward the cathode and falling into the forevacuum space should be greater than the number of molecules returning as result of diffusion. This condition is fulfilled, if the formation of ions is suf-

1. Sorption is called various type of entrapment of molecules and gas ions by the surface of liquid or solid bodies.

ficiently intensive, and depends in addition, upon the linear dimensions of the pump's discharge tube. Calculation[1] showed that at a 25 cm long tube with a diameter of 2 cm the necessary force of the discharge current should be of the order of 10 amp. To obtain such currents is used an incandescent cathode. But the task lies not only in the number of ionizing electrons; it is also necessary to increase the probability of their collisions with gas molecules.

At low pressures ($10^{-3} - 10^{-4}$ mm Hg) when the central path of electrons between two collisions is comparable to the dimensions of a vessl, electrons not colliding with molecules would have fallen on the anode and walls of the vessel and because of this they could not have participated in the process of gas ionization in volume. A raise in time of electrons remaining in the discharge is done by using a special geometry of the discharge interval and by placing the discharge in the outer magnetic field.

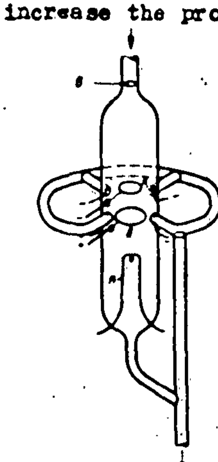

Fig.1.Schematic of an ion pump with incandescent cathode; operation is based on the forcing out of the gas.

Mode of operation of the ion pump,based on the forcing out, can be understood from fig.1.. The anode in form of a ring (A) is placed between two cathodes. One cathode - incandescent filament (K), the other one - cold one (K_1). The magnetic field, directed parallel to the axis of the system, compels the electrons to move along the spirals and prevents their escape to the anode. Flying through the circular anode, the electrons fall into a retardation field of the second cathode and are repulsed in reverse. In this way, the combined action of two fields (electric field of discharge interval and longitudinal magnetic field) lead to oscillations of electrons between the cathodes.

1.See H.Schwarz,Review of Scientific Instruments,vol.24,1953, p.371

As result the time the electrons remain in the volume increases, and the ionization of the gas appears to be sufficiently intensive. Consuming energy for ionization during collisions with molecules, the electrons gradually escape to the anode. The ions from the discharge are directed toward negatively charged circular electrodes, situated in the side sections of the tube; they become neutralized there and removed by the forevacuum pump. Near the entry to the exhausted volume is placed a positively charged electrode (B) serving for the prevention of retro falling of ions into the zone of high vacuum. This type of pump begins functioning at a pressure of about 10^{-3} mm Hg minimum pressure attainable by this pump- $5 \cdot 10^{-6}$ mm Hg. Rate of pumping - 0.5 l/sec[1].

When it becomes necessary to pump out larger volumes, or under conditions of gas circulation, pumps of greater capacity are used.

In fig.2 is shown a more powerful pump of analogous construction[2]. Its pumping rate equalled 7000 l/sec, minimum pressure, produced by it, was $1 \cdot 10^{-6}$ mm Hg. The necessary greater discharge current (10-20 amp at a voltage of 300-400 v) was obtained by continuous running the gas into space, situated close to the incandescent cathode, where the pressure was kept at a level of $5 \cdot 10^{-4}$ mm Hg, and also thanks to the action of the outer magnetic field, promoting ionization of the gas. The discahrge tube was sufficiently long to hamper reverse diffusion of the gas from the zone of the fore vacuum into the exhausted volume. Total power required by pump for filament incandescenc feeding the tube and magnet, equalled 42 kw.

One of the deficiencies of the above discussed types of ion pumps appears to be the relatively narrow working range of pressures (10^{-3} - 10^{-6} mm Hg); another shortcoming -use in role of cathode of an incandescent filament, evaporation of which in vacuum reduces the service life of the pump.

1. Rate of pumping is determined by the volume of gas removed by the pump per unit of time at given pressure.
2. See I.S.Foster, H.Lawrence, F.Lofgren: Review of Scientific Instruments, vol.24, 1953 p. 3.

In many instances when studying the physical and chemical properties of surfaces (determining the work of electron output, secondary electron emission, study of the sorption process, as well as the preparation of pure alloys, monocrystals, semiconductors) presence of smallest traces of oil vapors and residual gases leads to the formation on the investigated surfaces of thin films, changing the properties of surfaces. In such investigations a vacuum of the order of 10^{-6} mm Hg is insufficient, ultrahigh vacuum is necessary (10^{-8} - 10^{-10} mm Hg). The obtainment of such vacuum with the aid of a diffusion pump or ion pumps, working on the principle of forcing out, is impossible, as results of reverse diffusion of the gas from the forevacuum volume.

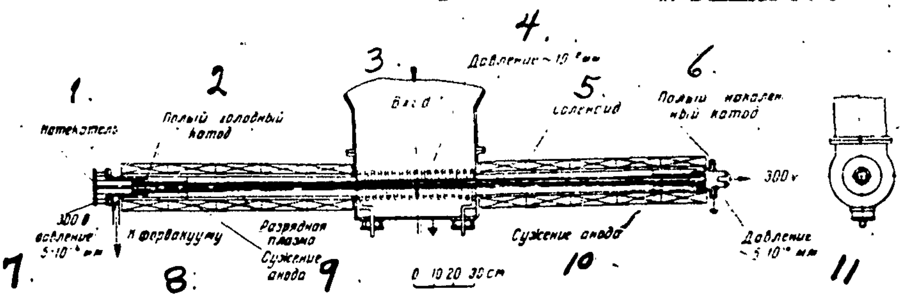

Fig.2. Powerful ion pump with incandescent cathode; mode of operation - forcing out the gas. 1-flow holder; 2-hollow cold cathode; 3-input; 4-pressure $\sim 10^{-6}$ mm 5-solenoid; 6-hollow incandescent cathode; 7-pressure $5 \cdot 10^{-6}$ mm ; 8-to forevacuum; 9-discharge plasma, narrowing of anode; 10- narrowing of anode; 11-pressure $5 \cdot 10^{-4}$ mm.

To improve the vacuum are used gas absorbers (getters), in particular alkaline metals, dusted at low pressures on the walls of the vessel. With the getters is possible to reduce the pressure of residual gases in the system by 2-3 orders. Gases capable of chemical reactions with dusted metal, are easily removed on account of chemical sorption. To remove inert gases they must be first ionized in the interior of the discharge tube. Consequently was introduced an ion pump[1] working on getting ionization atoms during thermal atomization of incandescent titanium filament in the discharge. The pump begins working at a pressure of 10^{-3} mm Hg giving a maximum vacuum of $5 \cdot 10^{-7}$ mm Hg and removes air and inert gases as well. The ions forming in the discharge under

1. See K. Herb, R. Davis, R. Dåvatra, D. Saxon: Physical Review vol. 89, 1953, p. 891.

the effect of the electric field are directed toward the walls of the pump, they penetrate into fresh layers of atomized metal and are held there by the forces of physical (or chemical) sorption, which leads to a reduction in pressure in the system. Specific vacuum rises to $5 \cdot 10^{-9}$ mm Hg and the rate of pumping - to several hundred liters per second, if the atomization of the incandescent titanium filament is combined with the ionization of the gas by electrons, oscillating in the volume under the effect of electric and magnetic fields [2].

Pumps for the obtainment of ultrahigh vacuum, the operation of which is based on the sorption of ionized gas in the discharge tube, are also described in certain reports[3].

As is known, absorption of gas takes place in ordinary electronic tubes. It is also observed during the operation of a trielectrode tube of an ionization manometer (fig.3). Electrons emitted by the filament, become accelerated in the field by a positively charged grid and, colliding with gas molecules, bring about ionization in the volume. Positive ions are trapped by the negatively charged collector and generate a current, serving for measuring the pressure. When the tube is in operation part of the ions is absorbed by the metal films, forming on the walls during evaporation of the fillament. In the process of removing ions acertain role is slao played by the negative charge of the wall, the magnitude of which is determined by the ratio of the number of electrons, falling on the wall, to the number of secondary electrons, liberated from same. Absorption of gas appears to be a shortcoming, when the tube functions in role of manometer (pressure gage); on the other hand, at low pressures this phenomenon can be utilized for the obtainment of ultrahigh vacuum.

2. See V.Alexeff and E.Peterson Vacuum Technology vol.5,1956,p.61
3. See D.Alpert, Journal of Applied Physics vol.24,1953, No.7, pp.860-876.

Measuring pressure of less than 10^{-8} mm Hg with the aid of an ordinary ionization tube (e.g.in LM-2 manometer) is hampered because of the fact, that during impact of electrons against the grid a soft x-ray radiation originates. This radiation, being absorbed by the collector, produced a photoelectron current, comparable in magnitude to ion current at a pressure of 10^{-8} mm Hg and lower.

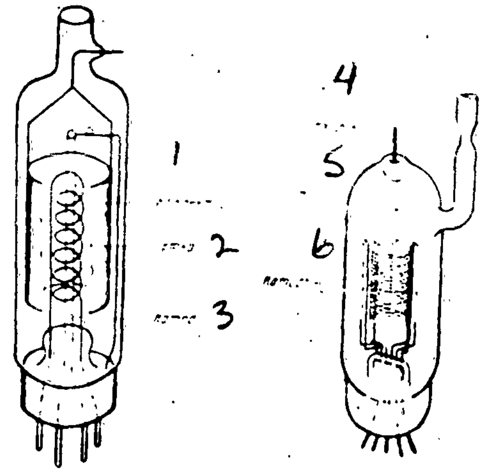

Fig.3. Schematic drawings of an installation of ionization tubes: left-tube of ionization manometer LM-2; right-tube of ion pump of Bayard-Alpert with incandescent cathode. Mode of operation- gas absorption. 1-collector; 2-grid; 3-cathode; 4-collector 5-grid; 6-cathode.

Measurement of ultrahigh vacuum, obtainable with the aid of an ionization tube, has become possible thanks to change in tube construction (see fig.3, right) Cathodes are situated on the outside of the grid. In the grid is placed a thin wire, serving as ion collector. Such an arrangement of electrodes causes the falling on the collector of a very small fraction of x-rays, emitted by the grid, which reduces the current of photoelectrons. The positively charged grid prevents the flying out of ions from the volume included in its interior, this leads to a rise in ion current, and consequently, also in the sensitivity of the manometer.

Measurements with such type of manometer showed that with the aid of an ionization tube, used in role of pump, the pressure can be reduced to 10^{-11} mm Hg in systems containing no lubricants, or in vessels, unsoldered at pressures below 10^{-6} mm Hg. The elimination of lubricants, appears to be a necessary condition for the obtainment of ultrahigh vacuum, was found to be possible thanks to the use in the high vacuum part of

the system metallic valves with metallic packings, allowing to carry out degasification of the system at high temperature.

Experiments have also shown that at repeated pumping of a volume of 1 liter from a pressure of 10^{-4} mm Hg to 10^{-10} mm Hg saturation took place within one hout of work, i.e. at further repeated startings of new gas portions the pump ceased pumping same. Saturation is explained by the change in wall change in the process of pump operation because during the absorption of gas is disrupted the initial ratio between the number of electrons falling on the surface and the number liberated from same. Positive metal ions, obtained during evaporation of incandescent cathode filament, possesses relatively low kinetic energy, therefore even a weak positive wall charge is capable of holding back the onslaught of ions.

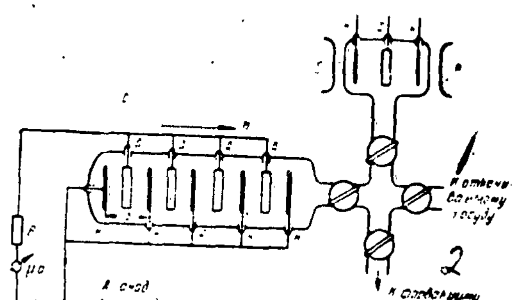

Fig. 4. Schematic of an ion pump with cold cathodes: a-single section pump; b-multisection pump. Mode of operation-absorption of gas. A-anode; K-cathode; 1-to ehausted vessel 2- to forevacuum

If pumping begins not with 10^{-4} mm Hg but with 10^{-7} mm Hg then the service life of the pump increases. The rate of pumping out equals 1/liter per min. The shortcoming of this pump is the use of an incandescent filament, limited working range due to high pressures (10^{-7} mm Hg) and the advent of saturation at a definite service life and that is why the instrumentis not a continuous action pump. In spite of all this, the pump found broad practical application, because with its aid can be obtained ultrahigh vacuum-of the order of 10^{-11} mm Hg, limiting only by the diffusion of helium from the atmosphere through the walls of the vessel[1].

Recently [2] was described a pump, the action of which is based on another principle.

1. In atmospheric air is contained helium less than 0.001% by volume.
2. See E.M.Reykhrudel', G.V.Smirnitskaya; A.I.Borisenko Radio Engineering and Electronics vol.1.1956, ed.2, pp.253-259.

This pump with cold electrodes,which eliminates deficiencies, connected with the presen of incandescent filament.A schematic of a discharge tube of one of the ion pump types isshown in fig.4,a. The discharge tube has a ring shaped anode on both sides of which are situated two disks, which appear to be cold cathodes. The use of the longi tudinal magnetic field allows to maintain the discharge without considerable increase in applied voltage at pressures of 10^{-6} - 10^{-8} mm Hg. The gas ionization mechanism by oscillating electrons in a magnetic field is analogous to the one described above.

In contrast to the discharge with incandescent cathode, in such type discharge sharp cathode sputtering does take place, i.e.atomization of the metal of the cathode under the effect of ion bombardment. The kinetic energy of the metal particles flying out from the cathodesis considerably greater,than in case of thermal evaporation of the incadescent cathode filament. The wall potential in the given pump does not substantially affect the gas absorption. The metal layer being continuously dusted on on the walls of the tube is absorbing gas intensively; consequently there is no saturation even at long lasting operation of the pump. The working range of the pump lies within limits of from 10^{-2} to 10^{-7} mm Hg; in individual instances the pressure can be reduced to 10^{-8} - 10^{-9} mm Hg. The power of the pump can be increased by parallel connecting a number of sections (see fig.4,b), whereby the rate of pumping out rises proportionally to the number of sections. During the operation of four sections the rate equals 1 liter/sec. The pump is not afraid of a random rise in pressure and penetration of chemically aggressive gases. It can be used for creating and maintaining vacuum in unsoldered systems. Being calibrated, it simultaneously controls the gas pressure in the system.

The modern state of high vacuum technology is such, that ion pumps- with respect to the power of pumping out as well as with respect to maximum pressure - is already now suitable for utilization in various lab conditions and in industry as well.

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